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# An assessment of solar energy potential in Kampuchea

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ABSTRACT

A satellite technique was adopted to assess solar energy potential in Kampuchea. The study aims to explore solar irradiation potential and distribution under the influence of Asian monsoons over land and a large water surface of a lake by using the satellite technique, with a relatively small spatial scale, which have never been accessed before. In this study, the solar irradiation potential over Kampuchea (10°N–14.5° N, 101.5°E–105°E) was estimated at interval of half a degree grid. The seasonal variations of mean daily solar irradiation in Kampuchea were measured during two Asian winter and summer monsoon seasons.

The results revealed that the mean solar irradiation depends more on orographic effects than on seasonal changes. During the winter monsoon, the local minimal means of daily solar irradiation were found on the great Lake Tonle Sap and on the northern, windward side of the Elephant Mountain with a range of 13–14 MJ $m^{-2}$ $day^{-1}$. The local maximal means of daily solar irradiation were found on the northwestern part of Kampuchea, with a value of 18 MJ $m^{-2}$ $day^{-1}$. In contrast, during the summer monsoon, the local minimal means of daily solar irradiation were, again, found on the same mountainous region of the Elephant Mountain, but the area of minimal means shifted to the southern side where it is the windward side of the mountain during the summer monsoon with a value of 12 MJ $m^{-2}$ $day^{-1}$. The local maximal means of the daily solar irradiation were found scattered over various areas: south of Lake Tonle Sap and at various places in the north and northwestern parts of the country, with a range of 18–19 MJ $m^{-2}$ $day^{-1}$. It was also found that a high mean of solar irradiation is generally associated with a low standard deviation, i.e., it is less in temporal variation.



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## 1. Introduction

Information on solar energy resource is often not available in many parts of the world. Moreover, a high intensity measurement of pyranometric networks is generally required to obtain high quality data of solar radiation for a relatively small spatial scale of observations. Unfortunately, such pyranometric networks generally do not exist especially in developing countries since the networks are not only costly but they also need intensive manpower for calibration, intercomparison, regular maintenance and continuous operation. One solution to this problem is to use a satellite technique to overcome such difficulty. Currently, meteorological satellite data become more and more common in uses to monitor and measure the amount of solar irradiation all over developed countries. However, assessments of solar energy potential by using this technique for most of developing countries are still rare. This is because of the complexity of this technique since it entails with highly calibre manpower, processing of large amounts of recorded satellite data, and requirement of advance equipments for data processing. As a result, hitherto, very few studies of solar energy potential have been reported from this part of the world, particular for relative small spatial scales less than one by one degree latitude and longitude.

In this study, solar energy potential over Kampuchea, a country located on Southeast Asian was assessed by using the satellite technique. The nature of the variation of solar irradiation as affected by the Asian monsoons and other effects due to a large water surface of the great lake and orographic surfaces were also investigated.

## 2. The study area

### 2.1. Geographic description

The study area is bounded by latitudes 10°N and 14.5°N, and longitudes 101.5°E and 105°E (see Fig. 1). It covers most of Kampuchea which is mostly a flat, alluvial low land area with the great lake "Tonle Sap" in the center. Lake Tonle Sap is the largest fresh water lake in Asia. The flat plain is bounded by low mountains to the north and moderately high mountains in the south, with the highest peak of 1750 m located in the Elephant Mountain range. Lake Tonle Sap provides water catchment for this area. For 6 months of the year during the wet monsoon season, central Kampuchea is waterlogged with marshes and swamps. This is the time when the Mekong River overflows its banks causing the area of Tonle Sap and the surrounding marshes to grow (by a factor of about seven) from 260 $km^2$ in the dry season to 1810 $km^2$ in the wet season. Fig. 1 shows map of the study area illustrating mountainous areas with elevation of 500 m or more.

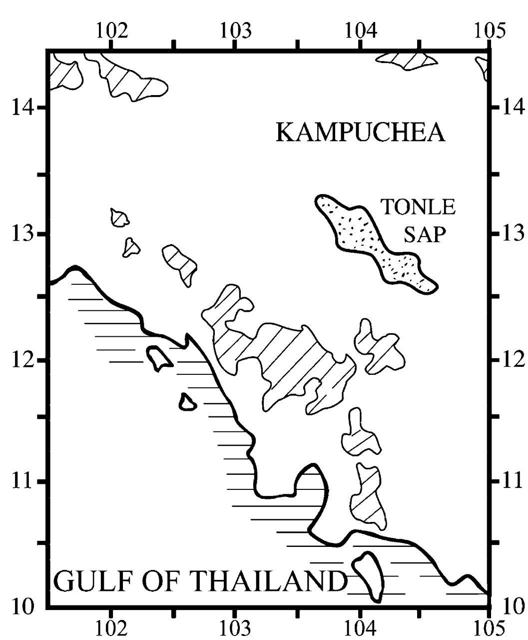


**Fig. 1.** Map of the study area; location of mountains with heights above 500 m is shown by diagonal lines. The location of Lake Tonle Sap is shown by dotted points.

### 2.2. Climate

Kampuchea is similar to most of the main land mass of Southeast Asia being influenced by two main prevailing monsoons, i.e., summer southwest monsoon and winter northeast monsoon.

The summer monsoon generally brings warm, moist, wet air mass to the area. By mid-summer, from May to August, the southwest monsoon spreads over the entire region. Rain falls everywhere. It is heaviest in places where tropical wet climate preponderate. Most of the areas have six to seven sunshine hours per day [1].

In contrast, the winter monsoon, originating from Siberia, generally brings dry and cool air mass. Starting from November to January, the northeasterly monsoon wind generally brings pleasant, balmy weather to the region. During this season, 8–9 h of sunshine per day can be found in most of the areas.

## 3. Methodology

### 3.1. Satellite data

Due to limited financial support for this study and the unavailability of current satellite data, sets of archived satellite data obtained by the Japanese stationary meteorological satellite, "GMS 3" in the past, during the years 1986–1987 were used in this study.

The data used were taken from the visible and infrared images of the whole earth disk observed by GMS 3 from 2:31 to 3:00 GMT, and from 5:31 to 6:00 GMT. The satellite scanned over Southeast Asia at about 9:45 and 12:45 local time, or at about 2:45 and 5:45 GMT.

### 3.2. Pre-processing of the data

The corresponding locations of the study area's target points in the satellite images were found by a process called navigation which projects ground locations onto the corresponding pixels in the images. The satellite data were then extracted from each of the target areas consisting of 15 × 15 arrays of pixels centered at each target point covering a square on the ground with sides approximately 43 km long. The center of each target point was evenly separated for half a degree over the entire study area. Estimates of global solar irradiation incident on the ground over each of the target areas were then calculated from the data of the visible and infrared pixel brightness in their pixel arrays.

### 3.3. The model

The model used for determining solar irradiation on the Earth's surface in this study was fully described in details previously in [2]. Hence, it is only summarized briefly here as follows:

$$\frac{G}{G_0} = C_1 N\left(\frac{A}{A_s - 1}\right) + C_2 \tag{1}$$

where $G$ is the downward global solar irradiation at the Earth's surface. $G_0$ is the extraterrestrial downward solar radiation. $N$ is the fraction of sky contaminated with clouds. $A$ is the visible albedo of the earth-atmospheric system. $A_s$ is the visible albedo of the earth-atmospheric system with a clear sky. $C_1$ and $C_2$ are the linear regression parameters of the above equation.

Eq. (1) can be qualitatively explained as follows. In the term $(A/A_s - 1)$ or its equivalence $(A - A_s)/A_s$, the numerator $A - A_s$ is the net visible albedo contributed by the clouds' optical thickness after subtracting the contribution from the ground's albedo. When the cloud is thick, $A$ is high; whereas when it is thin, $A$ approaches close to $A_s$ and is equal to $A_s$ for clear sky condition. The denominator $A_s$ is normalized to the fraction to compensate for variation of ground albedo $A_s$ which varies from place to place.

$N$, the fraction of sky contaminated with clouds, can be determined from the satellite's infrared data from the equation:

$$N = \frac{I_s - I}{I_s - I_c} \tag{2}$$

where $I$ is the mean infrared radiance over the target area, $I_s$ is the modal peak at high temperature taken under a clear sky condition, $I_c$ is the radiance of the cloud contaminated columns and is defined by

$$I_c = I - \sigma. \tag{3}$$

$\sigma$ is the standard deviation of the infrared radiance.

Eqs. (2) and (3) can be qualitatively understood as follows: under clear sky condition $I$ is close to $I_s$ and the calculated value of $N$ is close to zero; when there are broken clouds over the target, $\sigma$ is large and $N$ lies between zero and unity; when the target is covered with a thick uniformly overcast sky, $\sigma$ is small compared with $I_s - I$, so $N$ is close to unity.

Eq. (1) was regressed with pyranometric data at Bangkok and Chiangmai during 26 May to 19 July 1986, and was verified for the validity of the prediction at Khonkaen and Ubon in Thailand which are about one thousand kilometers from Bangkok during 26 May to 2 October 1986. It was found that the daily global solar irradiation could be estimated with a standard error of less than 14% of the mean using the satellite data.

## 4. Processing of data for the study area

In this study, full disk satellite images from GMS 3 were extracted focusing only on the study area as mentioned in Section 3.2. Since the variations of climate over Southeast Asia are controlled by the two principal monsoons, the northeast monsoon in winter and the southwest monsoon in summer, the data were subdivided into three 1-month periods for each monsoon season in order to ascertain their putative seasonal influences over solar radiation. Because of the research's budget limitation, only a few days were sampled each month during the period of the study of 1 year. Satellite images were taken for 9–11 days a month, they were quasi-randomly chosen depending on the availability and quality of the images.

The first set of images was collected during the winter monsoon months of November 1986 (10 days), December 1986 (11 days) and January 1987 (9 days). The second set of images was collected during the summer monsoon months for 16 May–15 June 1987 (11 days), 16 June–15 July 1987 (9 days), and 16 July–15 August 1987 (11 days).

Eq. (1) was regressed with pooled pyranometric measurement data of daily global radiation during November 1986–January 1987 at Chiangmai, Khonkaen, Ubon and Bangkok (each of the stations are about six hundred to one thousand kilometers apart) to determine the regression parameters $C_1$ and $C_2$. During May–August 1987, only the pyranometric data at Bangkok were used to regressed with Eq. (1) because of delays in the collection of pyranometric data from remote stations. Nevertheless, earlier tests of the model [2] have shown that the parameters found at one or two stations are applicable elsewhere in the study area. The equation was then used to estimate global solar irradiation over the target points at each half-degree in the study area in Kampuchea bounded by latitude lines 10°N and 14.5°N, and by longitude lines 101.5°E and 105°E. The regression results showed that the rms errors vary between 5.7% in the least cloud-covered months to 11.6% of the mean in the most cloud-covered month.

## 5. Results

Figs. 2 and 3 show the estimated seasonal means of daily global solar irradiation, and Figs. 4 and 5 show the associated seasonal

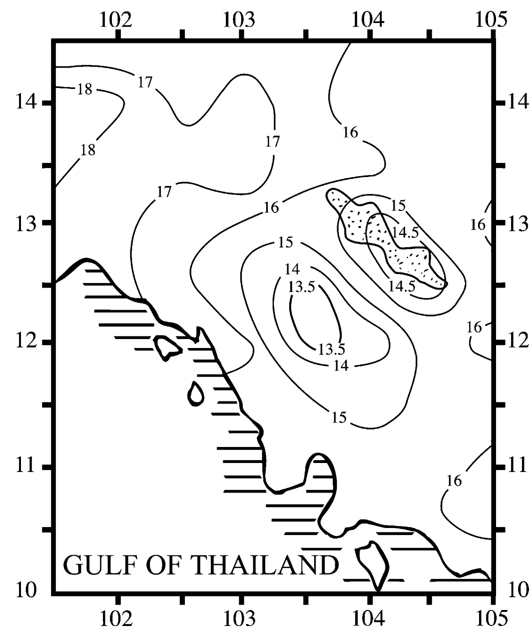


**Fig. 2.** Seasonal mean of daily solar irradiation in winter monsoon (MJ m$^{-2}$ day$^{-1}$). The dotted area is Lake Tonle Sap.

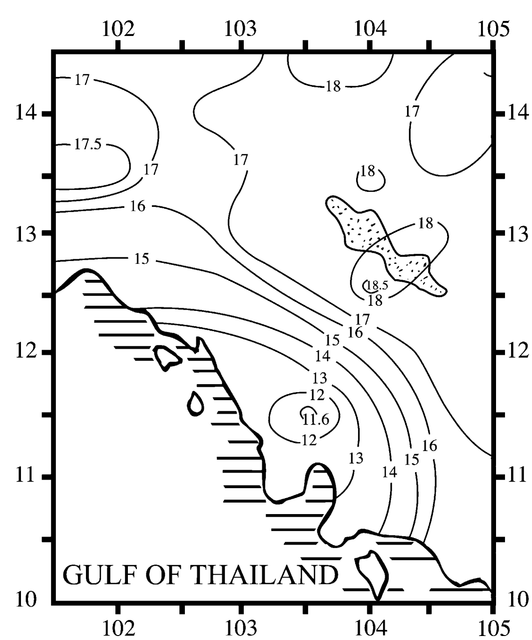


**Fig. 3.** Seasonal mean of daily solar irradiation in summer monsoon (MJ m$^{-2}$ day$^{-1}$). The dotted area is Lake Tonle Sap.

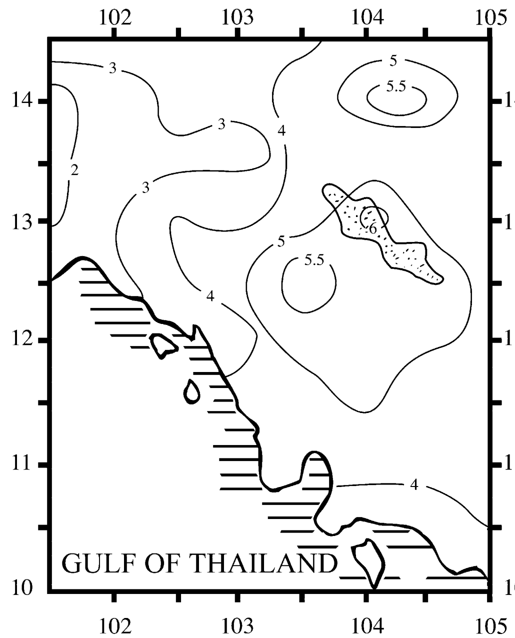


**Fig. 4.** Seasonal standard deviation of daily solar irradiation in winter monsoon (MJ m$^{-2}$ day$^{-1}$). The dotted area is Lake Tonle Sap.

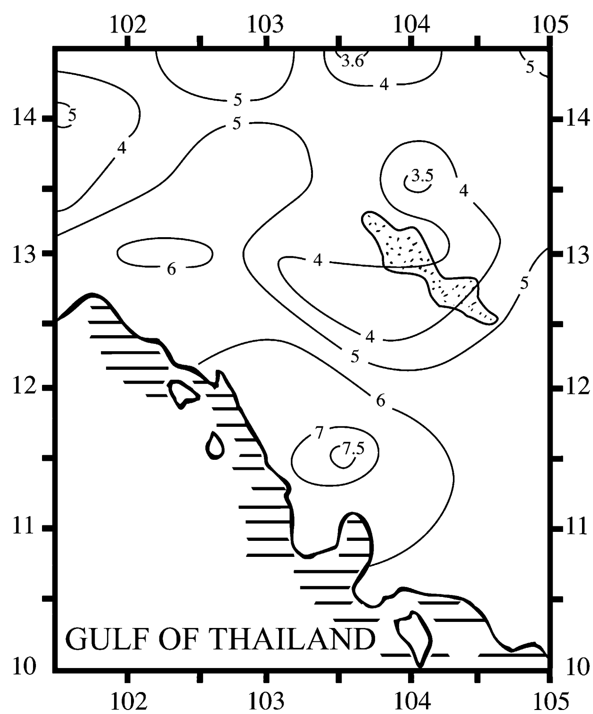


**Fig. 5.** Seasonal standard deviation of daily solar irradiation in summer monsoon (MJ m$^{-2}$ day$^{-1}$). The dotted area is Lake Tonle Sap.

standard deviations of daily solar irradiation over the study area during winter and summer monsoon months, respectively.

## 6. Discussion

It is important to note here that the data sample which has been used represents only one particular year and therefore the results presented are only valid for that specific year and cannot be generalized to other years. Nevertheless, this study suggests magnitude ranges of solar energy resource in this country. In addition, some interesting points concerning the nature of solar irradiation variation, as affected by seasons and topography of the study area, were also found.

**Table 1**
Maximum and minimum of monthly mean daily solar radiation (MJ m$^{-2}$ day$^{-1}$) over the study area (10°N–14.5°N and 101.5°E–105°E).

| Month | Min | Max | Differences of extremes | No. of sampling days |
|---|---|---|---|---|
| November | 10 | 19 | 9 | 10 |
| December | 14 | 18 | 4 | 11 |
| January | 16 | 19 | 3 | 9 |
| Mid-May–mid-June | 14 | 20 | 6 | 11 |
| Mid-June–mid-July | 9 | 18 | 9 | 9 |
| Mid-July–mid-August | 10 | 19 | 9 | 11 |

### 6.1. Magnitude

The ranges of mean solar radiation in the study area are shown in Table 1 for three 1-month periods of the two Asian monsoon months. This table also shows the extremes of the monthly mean daily solar irradiation and their differences over the study area.

Table 1 shows that the ranges of the difference between the maximum and the minimum means over the spatial study area of each month vary from 3 MJ m$^{-2}$ day$^{-1}$ in the relatively clear sky months to 9 MJ m$^{-2}$ day$^{-1}$ in the cloudy sky months.

It is interesting to note on the corresponding locations of these extremes as a function of seasonal variation as follows:

During the winter monsoon season, the maxima monthly means of daily solar irradiation were found in the northwestern region of the study area, and the minima were found in the southern region of the study area, particularly somewhere in the grid points of 12°N, 103.5°E and 12.5°N, 103.5°E. This result is not surprising since the grid points correspond to the mountainous region in Kampuchea where the highest mountain peak of the country is located at around 12°N, 103.5°E.

During the summer monsoon season, the maxima monthly means of daily solar irradiation were found in the northwestern and the northern region of the study area, and the minima monthly means of daily solar radiation again were found at the same location as that found in the winter monsoon season but shifted to the opposite windward side of the same mountain peak.

The orographic effect of high mountain ranges in the southern region of Kampuchea is quite pronounced. The orientation of the mountain ranges is almost normal to the directions of prevailing winter and summer monsoon. Hence, it enhances the convective of cloud activities. As a result, the lowest mean solar irradiation over the study area is found here.

### 6.2. Spatial variability

#### 6.2.1. Seasonal influence

Figs. 2 and 3 illustrate clearly that the spatial variations of mean solar irradiation in the area close to the mountainous southern region are much higher than those in other regions. The high spatial variations in this region were found in both monsoon seasons. This implies that the effects of orography are more dominant than the effects of the seasons.

#### 6.2.2. Lake influence

An interesting feature during the winter monsoon is the influence exerted by the great Lake Tonle Sap at the grid point around 13°N, 104°E. Here the mean daily solar irradiation was lower than over neighboring land areas around the lake, whilst its standard deviation was higher. This feature was pronounced in the early winter month in November. It would appear that, during the early month of the winter monsoon, cloudiness was produced

when the cool dry northeast monsoon passed over the relatively warm lake and the surrounding marshes. Thus, the lake enhanced cloud activity in the atmosphere and gave low values of solar irradiation over the lake (see Fig. 2).

These observations may be compared with those found by Gautier [3] who used GOES satellite images to map mean values of daily solar irradiation over Lake Ontario in North America during the period of April–December 1978. In the spring, the water of Lake Ontario was colder than the air; therefore, the atmosphere was more stable over the lake than over the land, inhibiting cloud activity. Thus, the mean solar irradiation over Lake Ontario was higher than surrounding areas. The result of Gautier [3] is quite similar to this study, except that the physical processes over Lake Tonle Sap are reversed, i.e., the warmer temperature of the water in Lake Tonle Sap enhanced cloud activity in the cool season.

### 6.3. Temporal variation of daily solar radiation

Hansen [4] has shown from surface measurements that the variability of solar irradiation with a time scale can be determined directly from the standard deviation of the mean solar irradiation which generally decreases with time averaging allowing one to compare the range of fluctuation in different seasons of a year.

In this study, Figs. 4 and 5 clearly illustrate that the spatial variability of the standard deviation over most areas in Kampuchea in winter is significantly less than that in summer, except for the areas on the windward side of the Elephant Mountain and around Lake Tonle Sap where they possessed low mean values of solar irradiation in winter.

During the winter monsoon, the dry cool winter monsoon generally brings stable non-convective air of balmy weather; hence, it suppresses cloud activities and gives relatively low ranges of the standard deviation variations in most areas. In contrast, during the summer monsoon, the warm humid summer monsoon is generally convective and unstable which generally causes high cloud activities, particularly in late afternoon. As a result, it causes high variability of solar irradiation and resulted in a wider range of standard deviation than in the winter. In the mountainous areas and Tonle Sap where the means of daily solar irradiation are low, the associated standard deviations are generally higher. This implies that in areas where cloud activities are high, not only does it attenuate solar radiation intensities but it also causes higher variation of solar radiation over time periods.

The magnitude of the standard deviation varies from place to place from 1 to 6 MJ $m^{-2}$ $day^{-1}$ in winter monsoon season, and from 3 to 7 MJ $m^{-2}$ $day^{-1}$ in summer monsoon season. Large standard deviation of the solar irradiation is generally found to be associated with low mean. The largest standard deviation is generally found at the windward side of the peak of the Elephant Mountain in the southern part of Kampuchea. It is located on the northern side of the mountain peak in winter, and shifted to the southern side in summer due to the change in the prevailing direction of the monsoon wind.

## 7. Conclusion

The results presented here giving the ranges of magnitudes and variability of daily solar irradiation in relatively small scale which has hitherto not been done for Kampuchea.

The study shows that the variations of daily solar irradiation over Kampuchea depend more on orthography than on seasonal changes.

Areas with low mean values of solar irradiation are generally associated with large standard deviations over a time scale. The mountainous areas generally have high spatial and temporal variability but with low means of solar irradiation, i.e., the variation of solar irradiation is high, both in terms of space and time scale. The effect of a large water surface, such as a large lake, is prominent when air and water temperature difference is large where it could either enhance or dampen cloud activities depending on whether air or water temperature is higher.

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